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PRESSURE LOSS COEFFICIENTS FOR BASIC AND MODIFIED TIE ROD COMPONENTS

(Title Unclassified)

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by

R. D. Foster
Fluid Flow Laboratory
Experimental Engineering

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Approved:

H. J. Fix, Supervisor

E. A. DeZubay, Manager

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SUMMARY

This report contains tie rod component pressure drop coefficients computed from data obtained in tests* in which gaseous hydrogen was used as the working fluid. Representative values of the coefficients are as follows:

Tie Rod Centering Bushing (Chamfered)	1.0 (0.012 in^2 flow area)
Tie Rod Centering Bushing (Unchamfered)	1.5-2.6 (flow area range 0.0006 in^2 - 0.005 in^2)
Tie Rod Holder	3.0-11.0 (flow area range 0.039 in^2 - 0.132 in^2)
Tie Rod Cone Support	1.0-1.5 (flow area range 0.032 in^2 - 0.0096 in^2)

The effect of leakage flow on the performance of the centering bushing was investigated.

ANALYSIS

The pressure drop coefficient as used herein is defined as

$$C = \frac{2\,g\,(\Delta P)}{\rho V^2} \tag{1}$$

where

C = pressure drop coefficient (dimensionless)

g = gravitational constant (ft/sec^2)

ΔP = static pressure drop across the tie rod component (lbs/ft^2)

ρ = density of the working fluid at inlet (lbs/ft^3)

V = average velocity of hydrogen in the tie rod component restriction (ft/sec)

The mass flow rate,of the working fluid was measured by a calibrated sonic orifice flow meter and is given as

$$W = KP_f/(T_f)^{1/2} \tag{2}$$

*NOTE: Preliminary data has been issued in WANL-TMI-552 and has been repeated here. R. D. Foster "Experimental Determination of Tie Rod Component Pressure Drop Coefficients" - WANL-TMI-552 3-63, CRD where

W = mass flow rate (lbs/hr)

K = flow constant $(^{\circ}R)^{1/2}$/psi-hr

P_f = flow meter pressure (psia)

T_f = flow meter temperature ($^{\circ}R$)

Equations (1) and (2) can be combined to give the following expression for the pressure loss coefficient of any component.

$$C = \left[\frac{8.3\,(10)^8\,(A)^2\,(\Delta P)}{RK^2}\right]\left[\frac{P_1}{(P_f)^2}\right]\left[\frac{T_f}{T_1}\right] \tag{3}$$

where

A = component flow area (in^2)

R = gas constant (ft lb/lb $^{\circ}R$)

ΔP = component pressure drop psia

P_1 = component inlet pressure (psia)

P_f = flow meter pressure (psia)

T_f = flow meter temperature ($^{\circ}R$)

T_1 = component inlet temperature ($^{\circ}R$)

It is to be noted that the coefficient was calculated on the basis of perfect gas relationships. Doing so results in a possible deviation of 1 to 2% from that calculated using real gas tables. The deviation is within the range of experimental accuracy of the instrumentation employed.

The Reynolds number as used herein is defined as

$$Re = \frac{\rho V d}{\mu}$$

where

Re = Reynolds Number

d = Equivalent diameter (ft)

$$\frac{4 \text{ cross sectional area}}{\text{wetted perimeter}}$$

μ = Viscosity of working fluid (lb/ft sec)

The tie rod centering bushing was tested with various leakage paths open and sealed in order to determine the effect of leakage on the pressure drop. The three (3) possible leakage paths are:

a) Through the split, in the case of the split bushing insert.

b) Through the annulus formed by the tie rod and the bushing insert. (Bushing insert - tie rod interface)

c) Around the edge where the bushing insert fits into the centering bushing. (Bushing insert - centering bushing interface)

The loss coefficients including the various leakages were based on the orifice flow area and the total mass flow through the bushing assembly.

APPARATUS TESTED

The various components tested are shown in the appendix in Figures 1, 2, 3, 4, and 5.

EQUIPMENT AND METHODS

The general test system is shown in Figure 6. The principle involved is that of measuring the pressure drop through a particular tie rod test piece for a known mass flow rate of gas passing through the test piece. The mass flow rate is determined from the gas pressure and temperature upstream of a calibrated sonic flow orifice. This data, together with the pressures and temperatures read as shown in Figures 5, 6, 7, 8, and 9, is evaluated with Equation (3) to obtain the pressure loss coefficient for the particular test piece mounted in the flow system.

RESULTS

Pressure loss coefficient for the various tie rod test pieces are on the order of those normally expected for the type of flow patterns involved.

Loss coefficients for the holders ranged from 3 for the 0.039 in^2 flow area, to 11 for the 0.132 in^2 flow area with the coefficient approximately proportional to the flow area for all the holders tested, Figure 10. The four holders tested covered the flow area range originally requested, Reactor Analysis Test Request (RATR) No. 6, and all holders had the slot-type flow openings shown in Figures 1 and 2.

The pressure loss coefficient of the first chamfered centering bushing tested was approximately 0.9, as shown on Figure 12. This bushing had a total flow area of 0.012 in^2, which was one-third of the smallest flow area specified in the original request, RATR No. 8. Because the desired range of pressure drops across the centering bushings were several times those recorded for the 0.012 in^2 total flow area, no tests were performed on chamfered bushings having larger flow areas; those bushings would exhibit even smaller pressure drops than those recorded for the 0.012 in^2 bushing. A series of unchamfered bushing having drastically reduced flow areas was then tested. The pressure loss coefficients for the unchamfered centering bushings ranged from 1.4 to 2.6, depending on the bushing size. Figures 13 thru 20 present the unchamfered centering bushing pressure loss coefficients.

Hot cone support coefficients varied from 1 for the 0.059 in. diameter holes to 1.5 for the 0.030 in. diameter holes, varying inversely with hole size. Figure 21 presents the results of the pressure loss coefficient tests on the hot cone supports.

Numerical test results are listed in Table 1.

DISCUSSION

Inlet pressure was varied over a wide range in the holder tests, Table 1, to determine any effect of inlet pressure on the loss coefficient. The results showed no definite change in the loss coefficient. The loss coefficients for the holders, Figure 10, exhibit an interesting trend in that the coefficients based on holder area decrease with decreased holder flow area. The holder assembly presents a complex flow path; a number of fixed flow restrictions exist in series with the holder slots on which the flow area is based (see Figures 1, 2, and 5 for the slot configuration). As the slot area decreases, the pressure loss at the slot increased for a constant mass flow rate and becomes large in comparison to the fixed losses. This makes the overall holder pressure drop primarily that of the slot itself. The trend with decreasing slot area is toward a loss coefficient for the slot alone. This coefficient is on the order of 1.5, a typical coefficient for a sudden contraction followed by a sudden expansion. The smallest loss coefficient on Figure 10 is approximately 3.0, for the 0.039 in^2 flow area. This indicates that the total flow losses, fixed plus slot, for the specific holder are approximately twice the loss for the slot alone. A holder with a flow area of 0.02 in^2, should exhibit a loss coefficient very close to 1.5. This trend is due to the fact that some of the flow restrictions other than the slots have flow resistances of approximately the same order of magnitude as those of the slots. If the loss coefficient is based not upon the slot area, but upon the annular area between the tie rod and the holder (0.048 in^2), it is found that as the slot area increases, the loss coefficient decreases. (Figure 11)

The chamfered centering bushing loss coefficient, Figure 12, is essentially that of a gradual contraction followed by a sudden expansion. The centering bushing tested simulated the gradual contraction with a chamfered inlet, and simulated the sudden expansion with a sharp edged exit. The loss coefficient is approximately 0.9. The bushing configuration is shown on Figures 1 and 3.

Pressure loss coefficients for the unchamfered bushing are presented in Figures 13 thru 20. Figures 13, 14, 15, and 16 show the effect of orifice diameter reduction, on the loss coefficient based on orifice flow area for a bushing having four (4) orifices. For hole diameters .020, .025, .029, and .040 inches, loss coefficients based on orifice flow area had nominal values of 1.73, 1.72, 2.26, and 1.73 respectively. No explanation can be offered for the sudden increase in loss coefficient for the .029 diameter bushing; however, the value is consistent with values which will be discussed later. A plot of orifice loss coefficient based on the annular area which exists around the tie rod in the unfuelled hex as a function of orifice diameter, is shown in Figure 17. As would be expected, as the orifice area increases, the loss coefficient based on tie rod annulus area decreases. Figures 18 and 19 show the loss coefficient for bushing with only two (2) orifices. The value for the bushing having 2-.040 inch nominal diameter holes is the same as that obtained for a bushing having 4-.040 inch nominal diameter holes. The results for the bushing having 2-.029 inch diameter holes is slightly higher than that obtained for a bushing having 4-.029 inch diameter holes. The .029 inch holes again exhibit the higher coefficients indicated previously.

Figure 20 shows the effect of leakage on the loss coefficient, based on orifice area, for a bushing having .029 inch nominal diameter orifices. The largest leakage flow is due to the split in the bushing.

The hot cone support loss coefficients are shown on Figure 21, and the general configuration is shown on Figures 1 and 4. The cone support is essentially a gas diffuser at the end of a flow tube. With a small diffuser total flow area of 0.0096 in^2, the gas flow must contract when leaving the relatively large flow tube and entering the diffuser. This results in the typical contraction-expansion loss coefficient of 1.5 as shown on Figure 21. When going to the other extreme of the 0.032 in^2 diffuser total flow area, the diffuser flow area is approximately equal to that of the flow tube, so that the gas no longer experiences a violent contraction when entering the diffuser holes. The loss coefficient now simply approaches that of a sharp edged exit, 1.0 as shown on Figure 21.

RECOMMENDATIONS

The tests reported herein give results for representative test pieces. However, individual parts as well as fits between parts will cause deviations from the figures given in this report. Since the coefficient for a circular opening is proportional to the fourth power of the diameter, small discrepancies in manufactured parts can result in large changes in the effectiveness of a particular component as a flow metering device. To obtain exact values for each assembly, it is necessary to test that assembly having the identical parts it will have in the eventual construction. This is especially important when considering split bushings. The coefficient can change appreciably for varying degrees of leakage through the split.

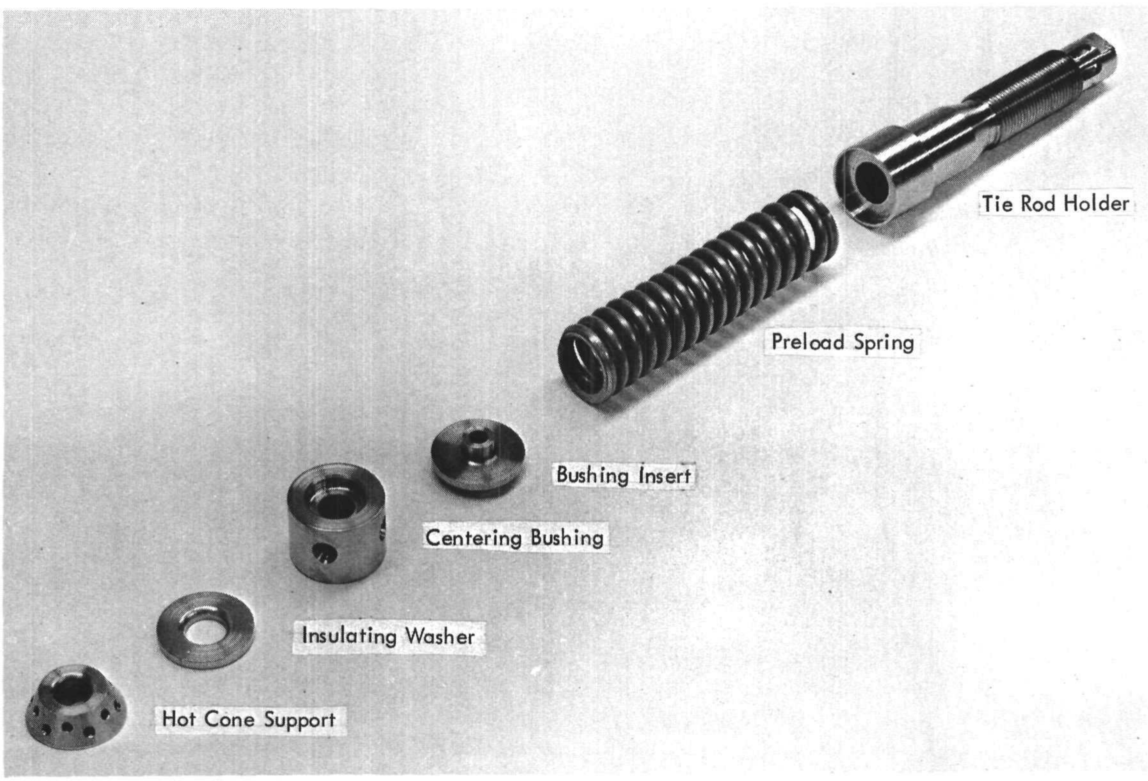

FIGURE 1. Tie Rod Test Components

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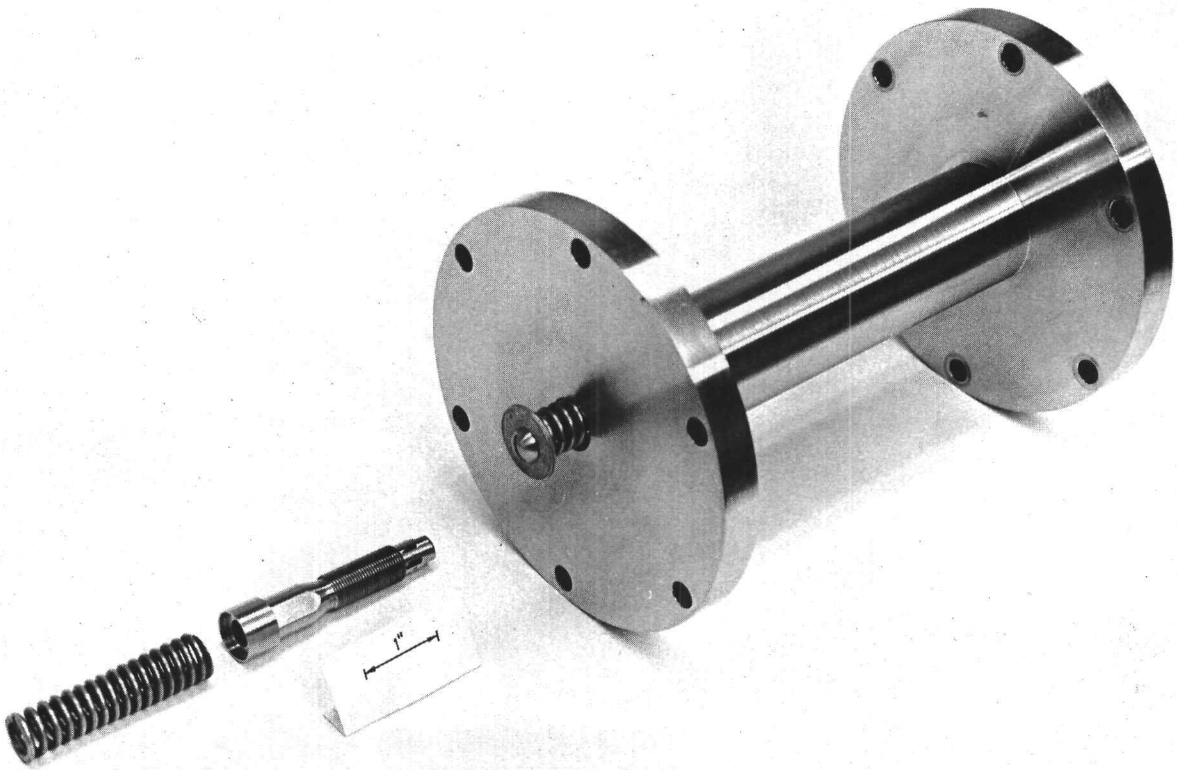

FIGURE 2. Tie Rod Holder Test Fixture

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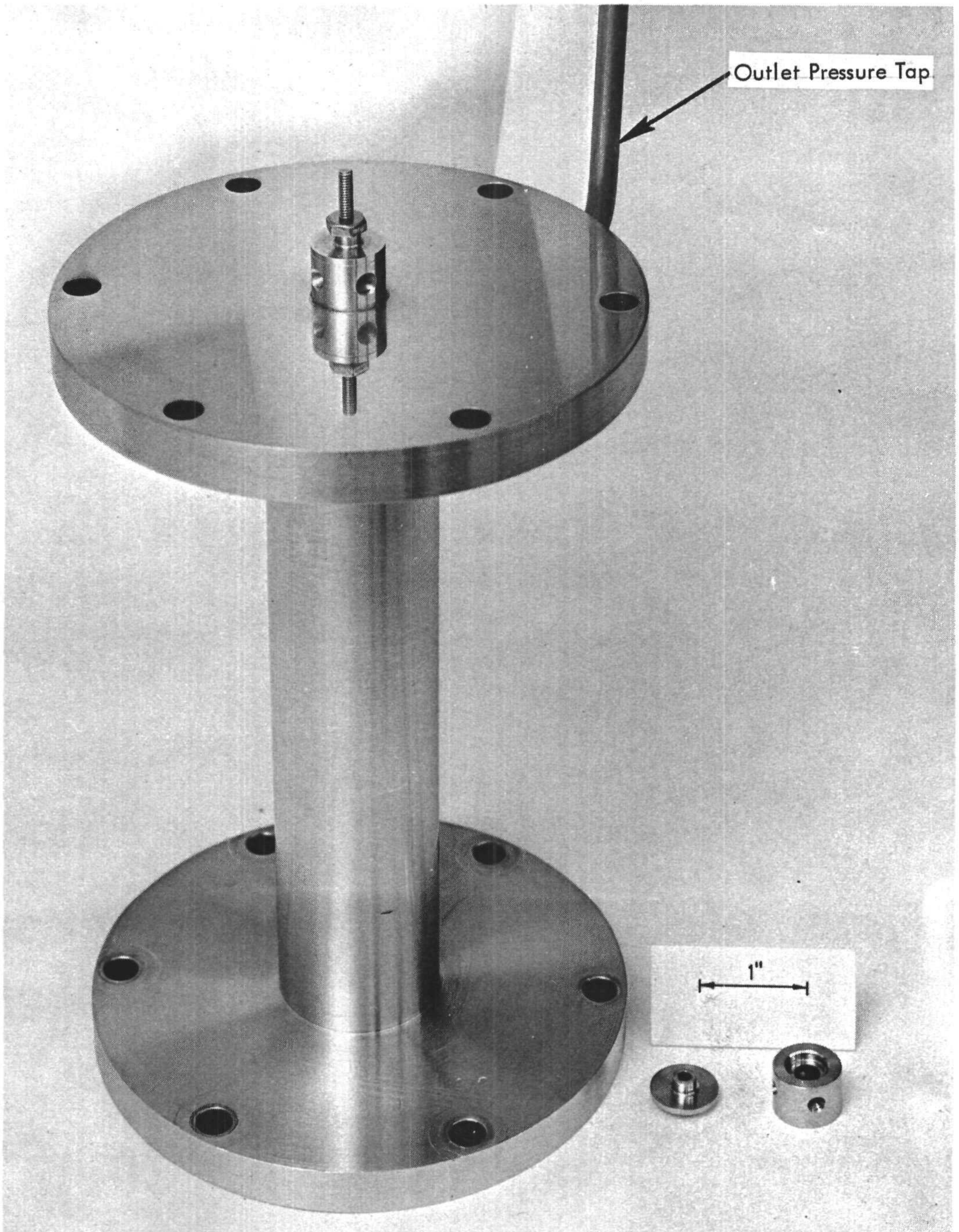

FIGURE 3. Tie Rod Centering Bushing Test Fixture

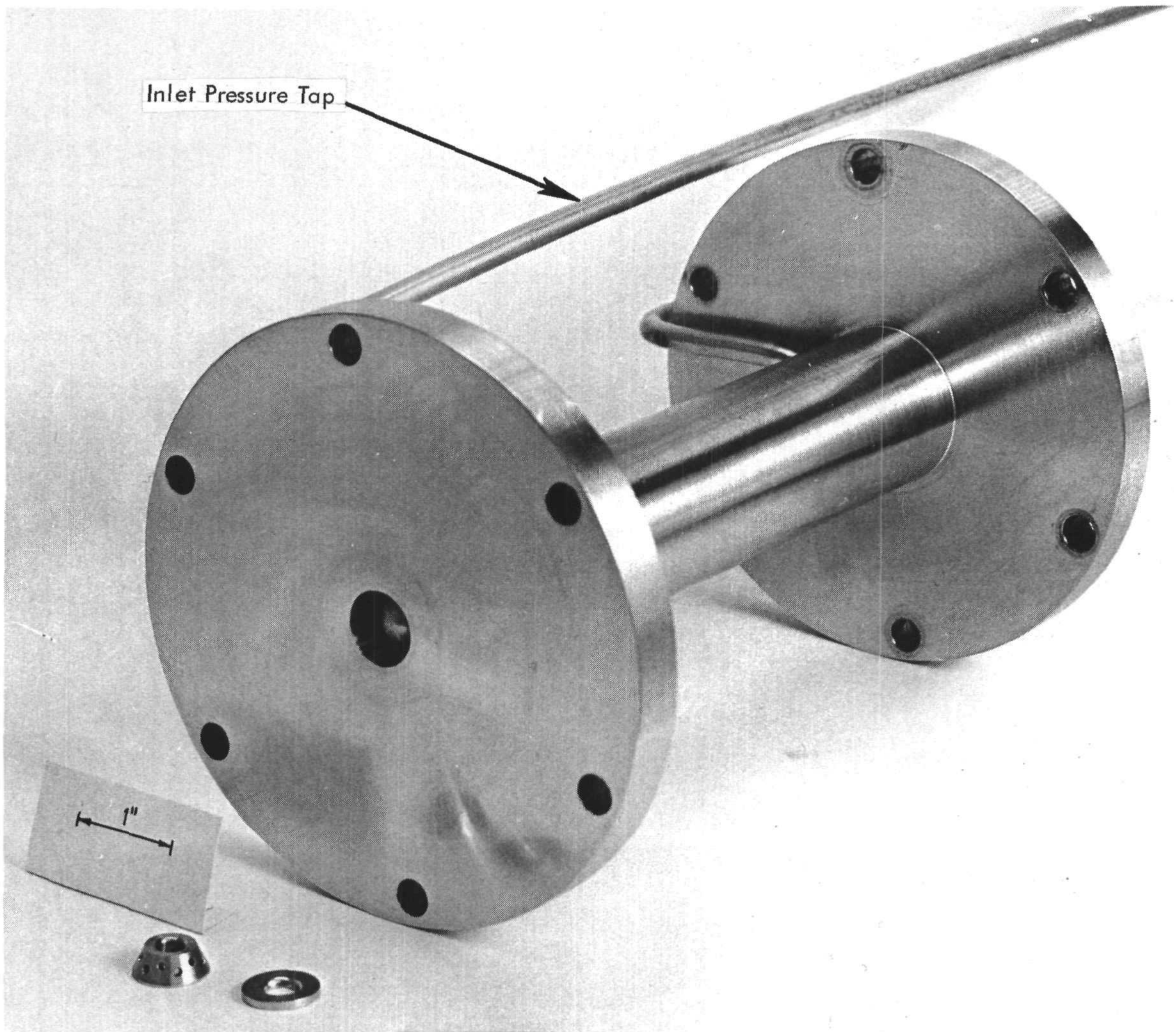

FIGURE 4. Tie Rod Cone Support Test Fixture

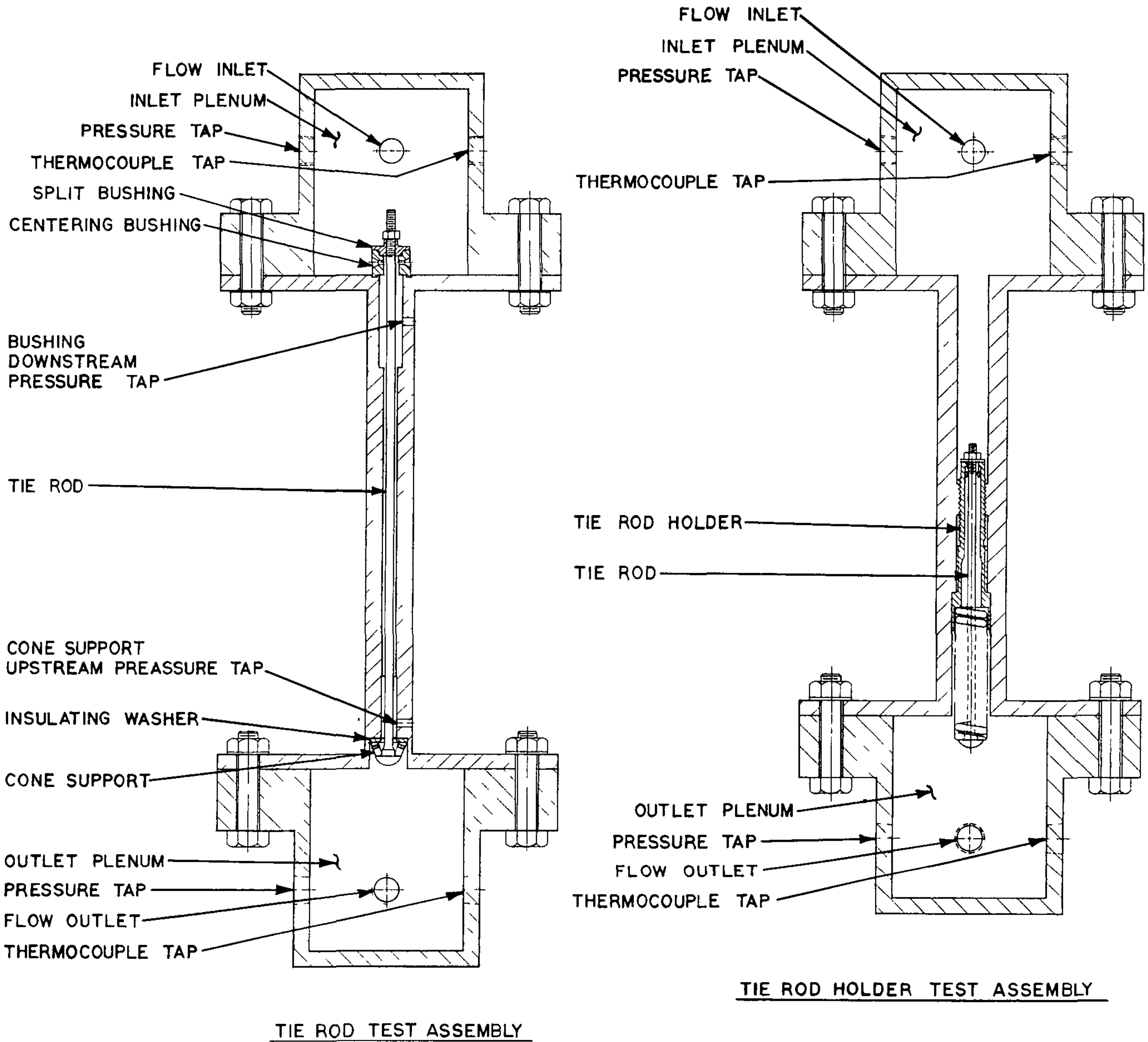

Figure 5. Tie Rod Component Test Assemblies

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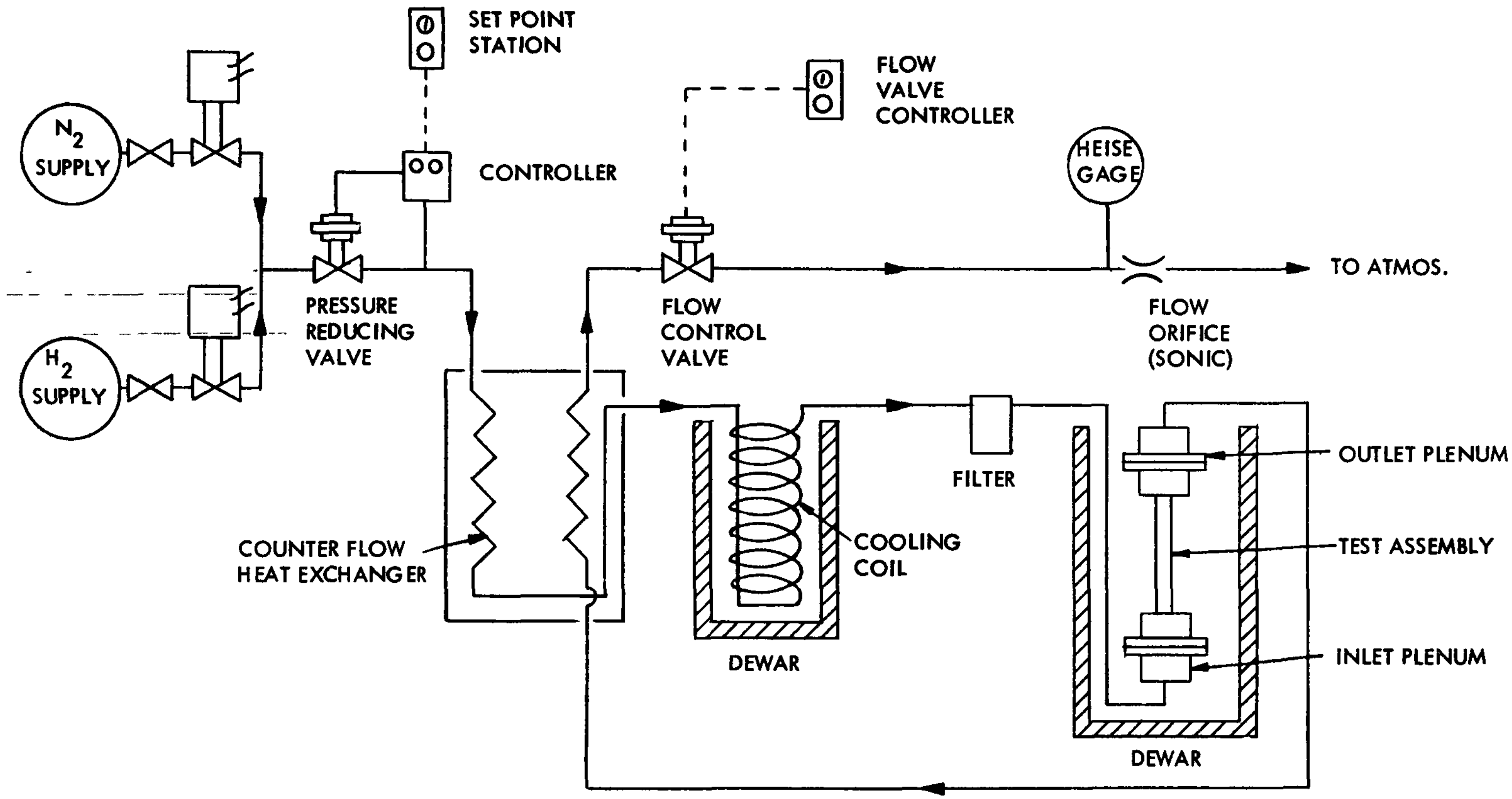

Figure 6. Small Scale Basic Flow System

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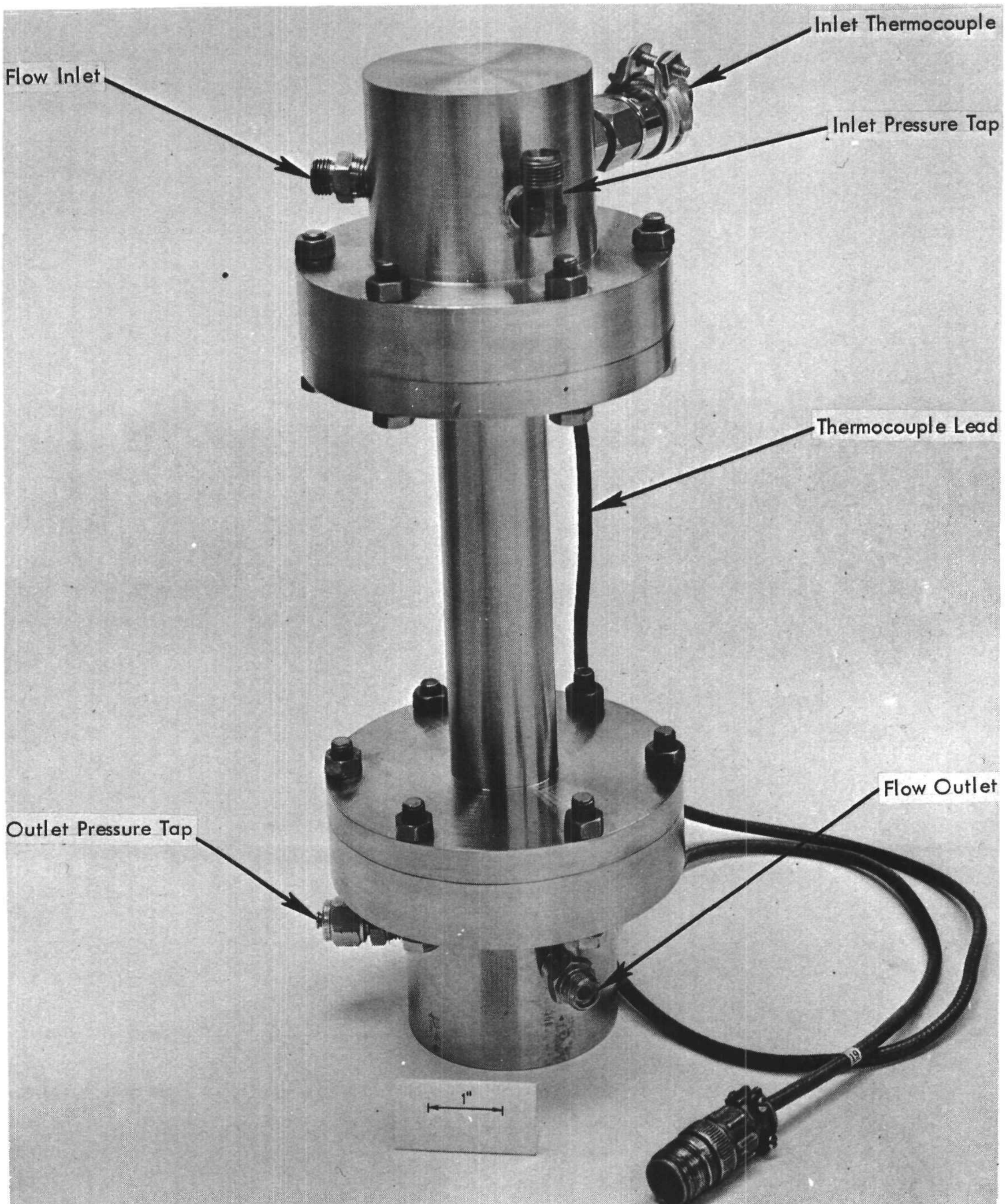

Figure 7. Tie Rod Holder Test Assembly

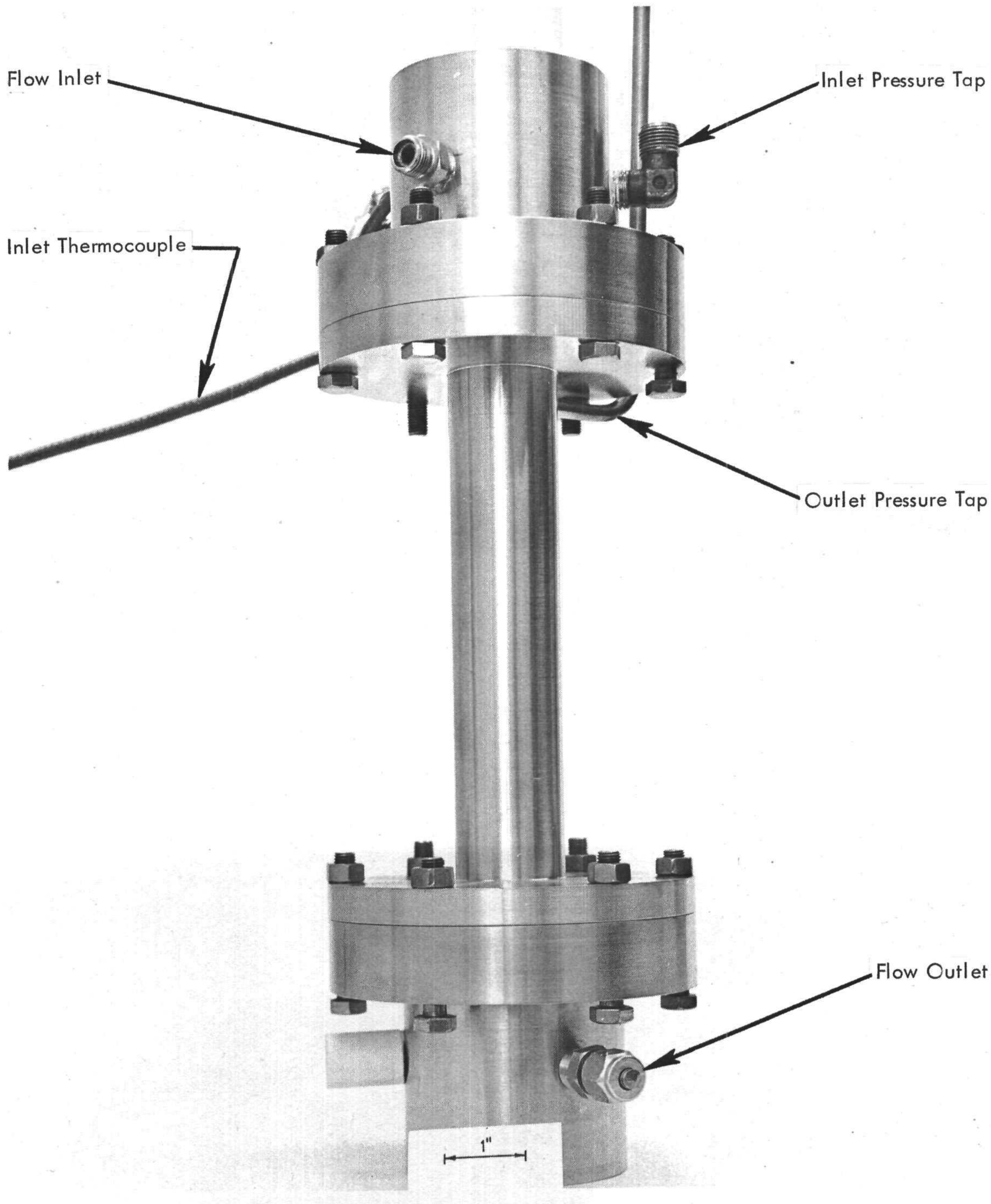

Figure 8. Tie Rod Centering Bushing Test Assembly

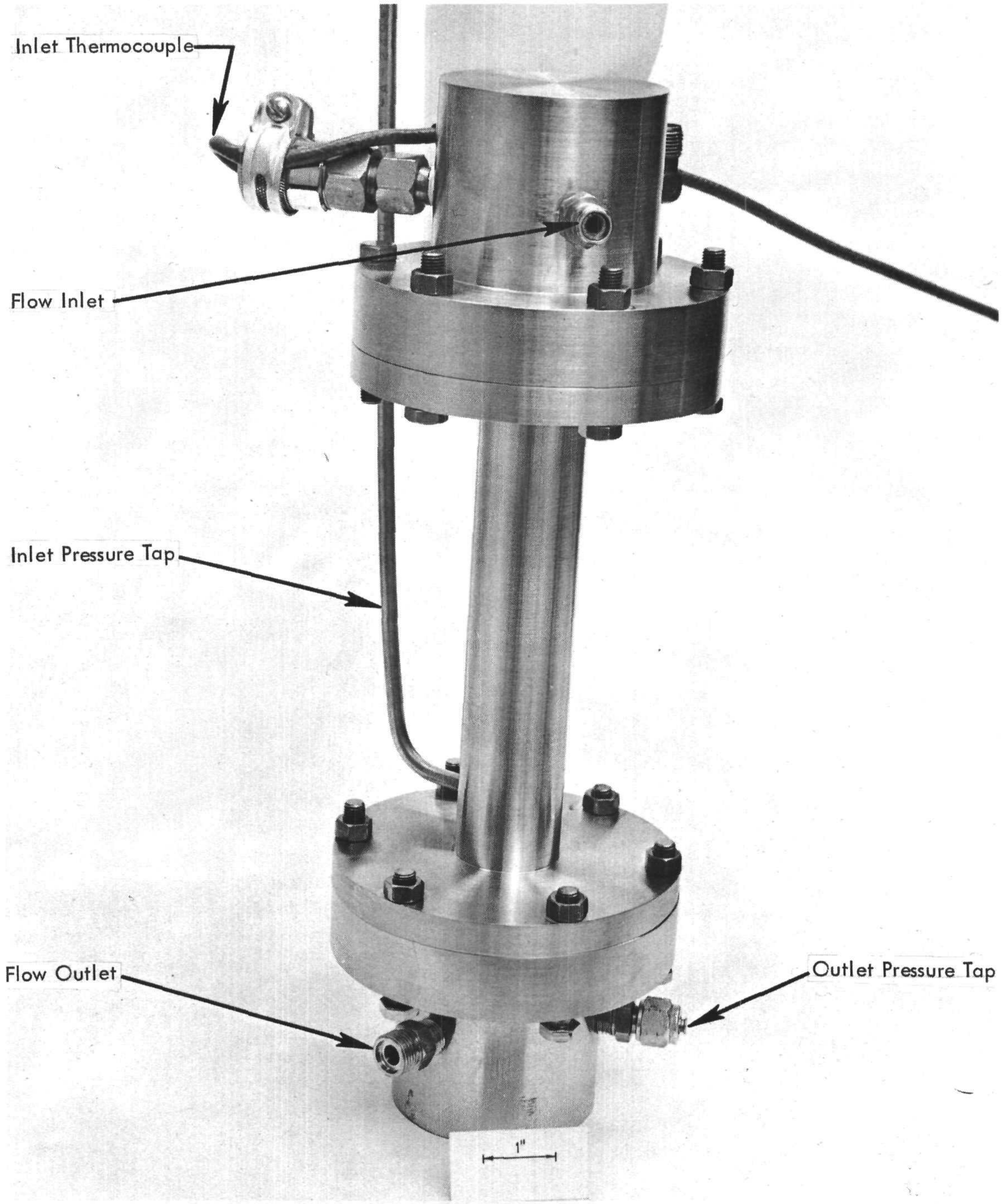

Figure 9. Tie Rod Cone Support Test Assembly

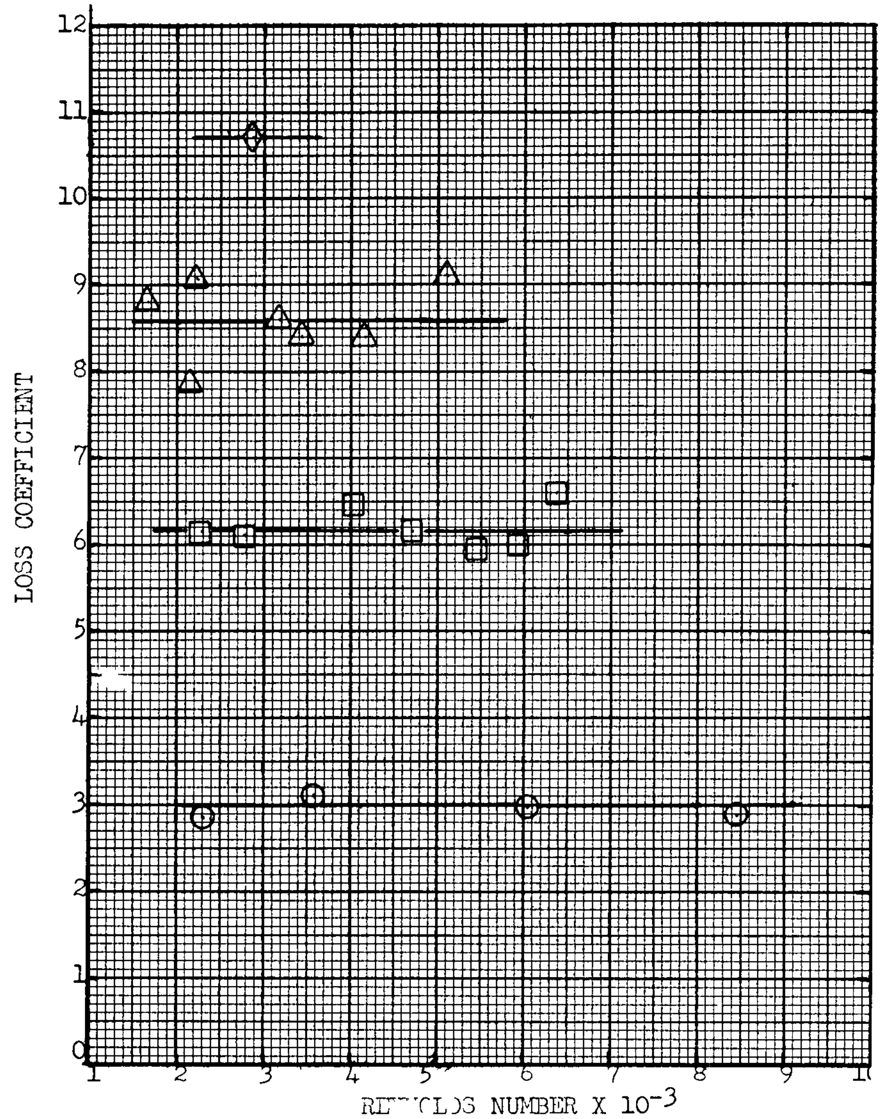

FIGURE 10
LOSS COEFFICIENT
(BASED ON SLOT AREA)
VS
REYNOLDS NUMBER
FOR THE TIE ROD HOLDER FOR VARIOUS SLOT AREAS

SYMBOL	○	□	△	◊
TOTAL FLOW AREA (IN^2)	.0394	.0780	.113	.132

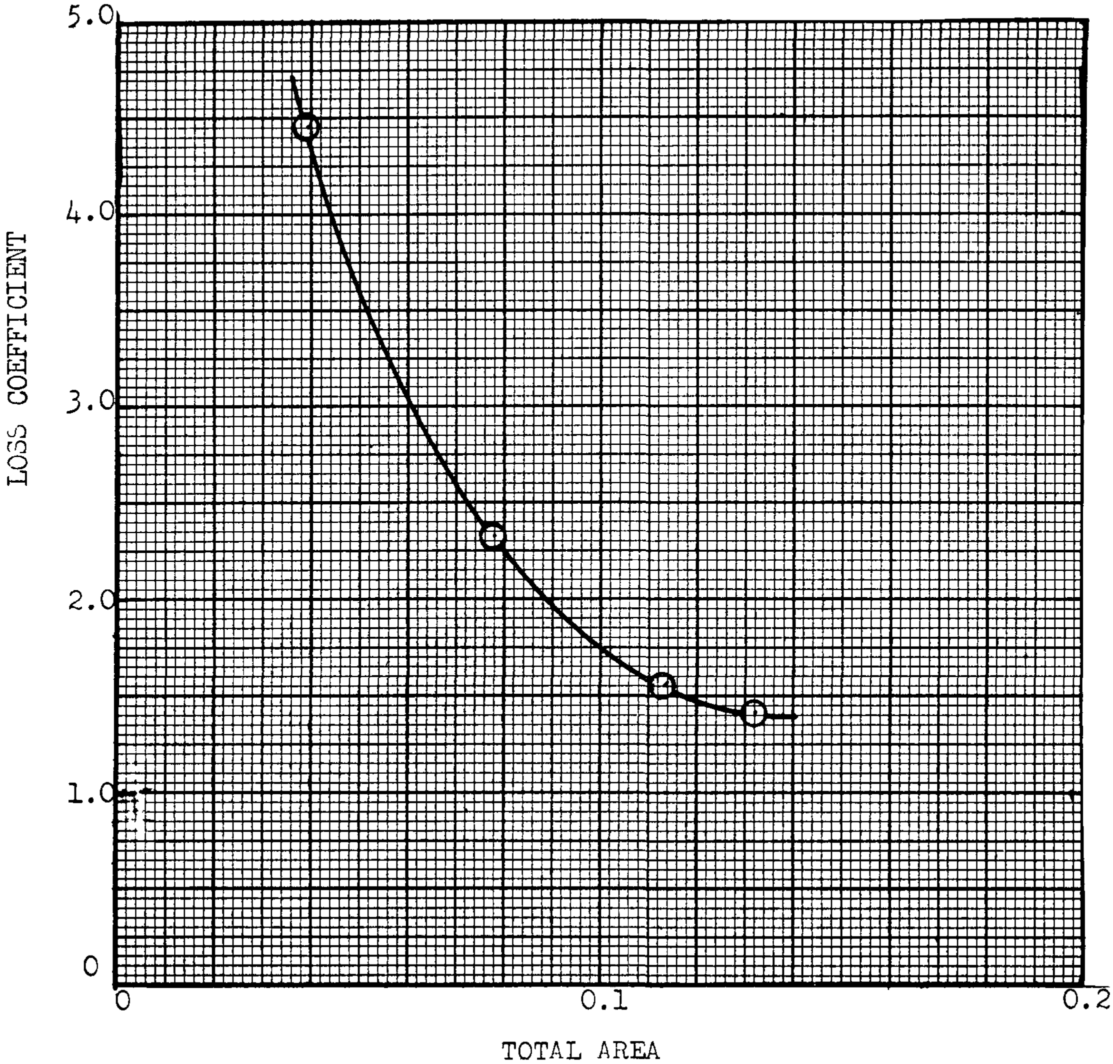

FIGURE 11

LOSS COEFFICIENT

(BASED ON ANNULUS AREA)

VS

TOTAL AREA (6 SLOTS) FOR THE TIE ROD HOLDER

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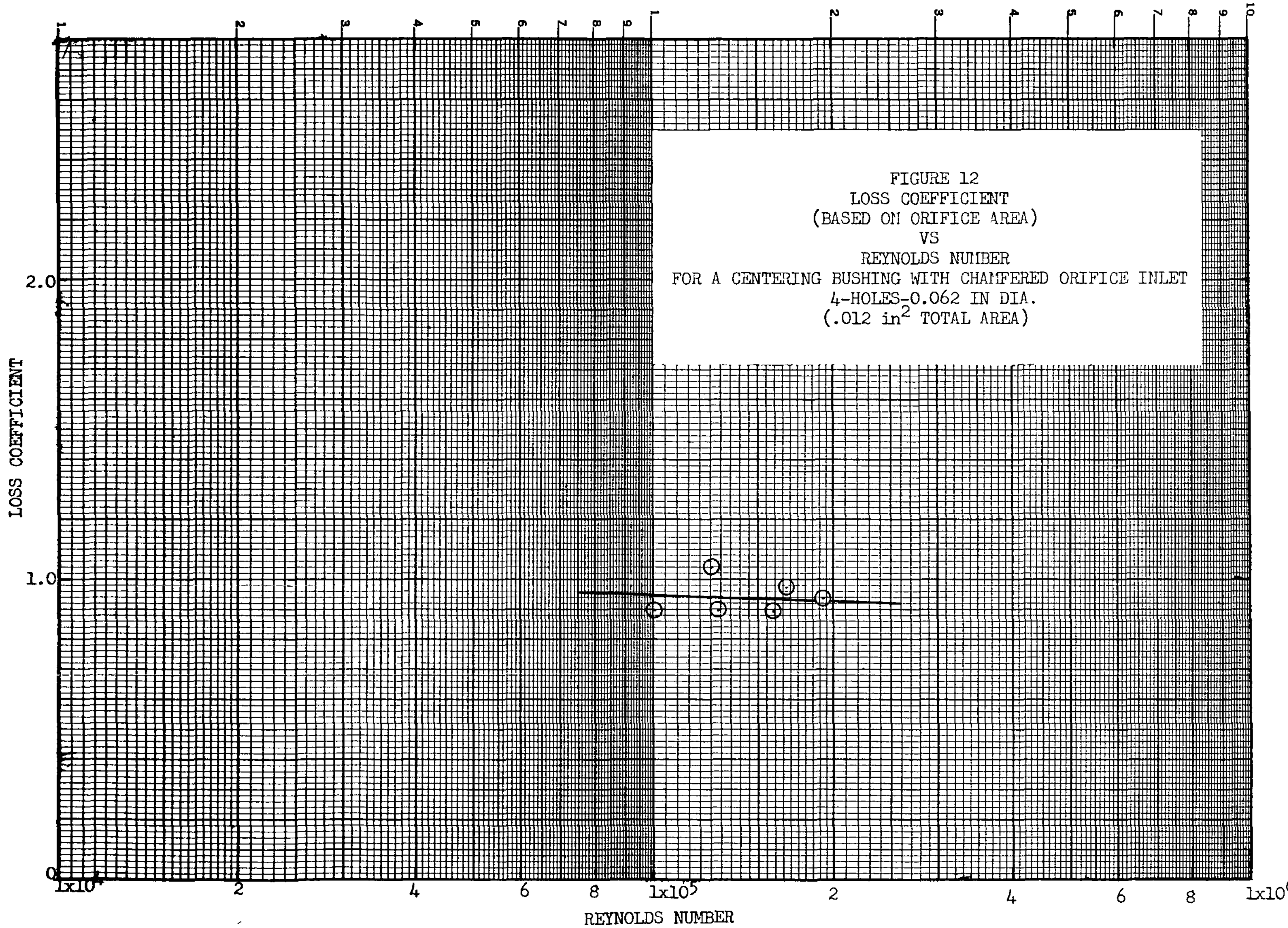

FIGURE 12
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A CENTERING BUSHING WITH CHAMFERED ORIFICE INLET
4-HOLES-0.062 IN DIA.
(.012 in^2 TOTAL AREA)

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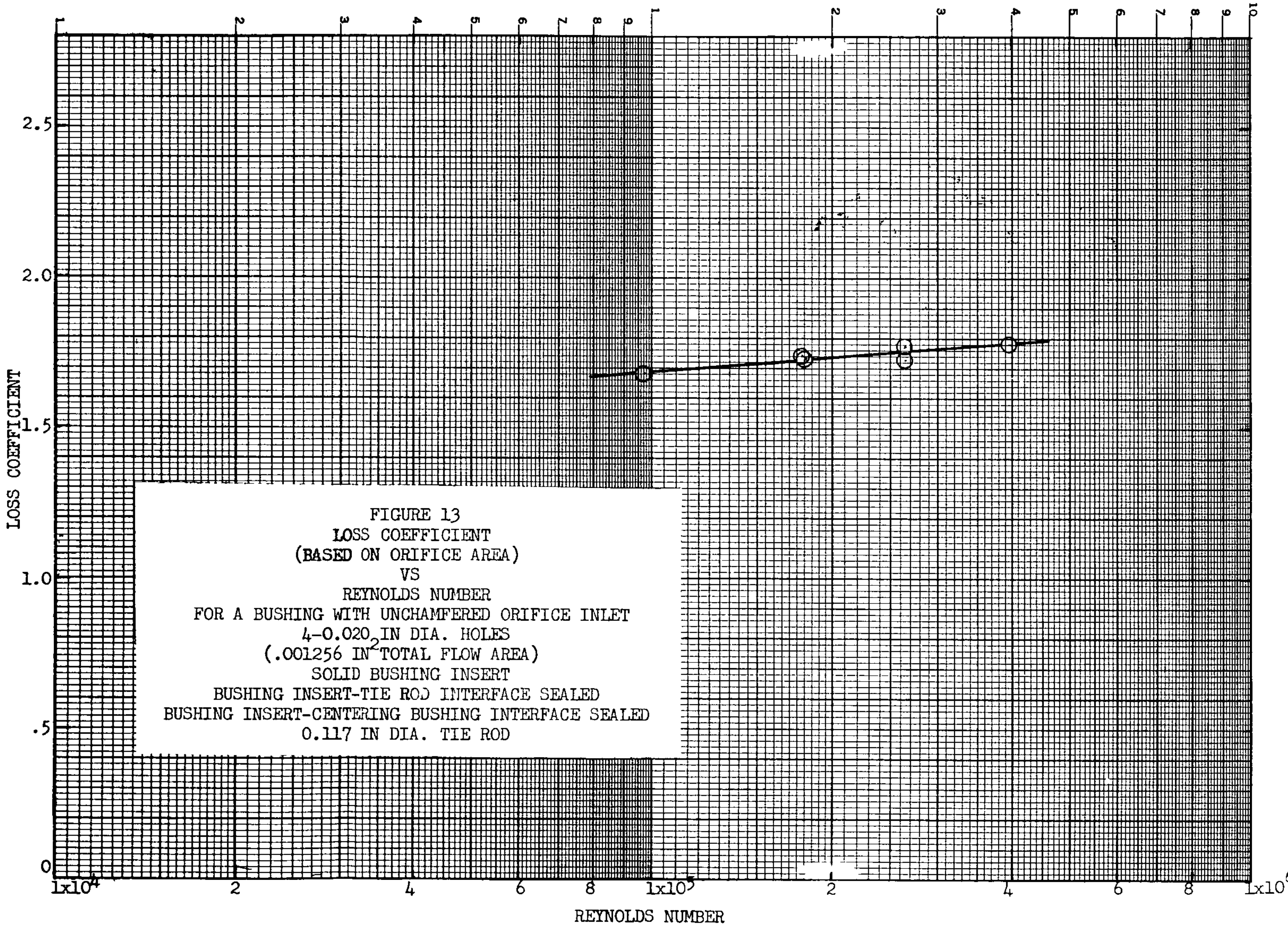

FIGURE 13
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.020 IN DIA. HOLES
(.001256 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN DIA. TIE ROD

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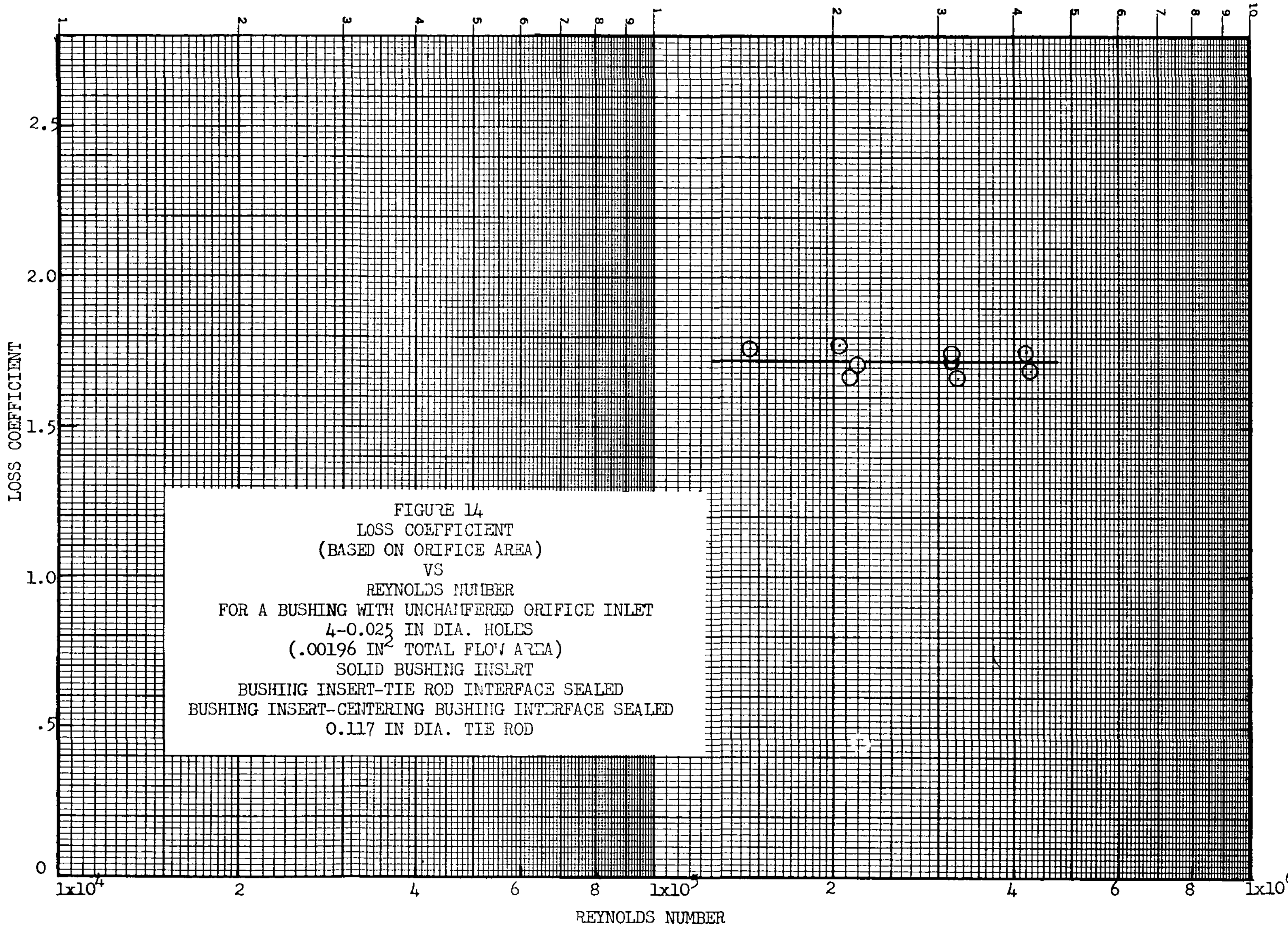

FIGURE 14
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.025 IN DIA. HOLES
(.00196 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN DIA. TIE ROD

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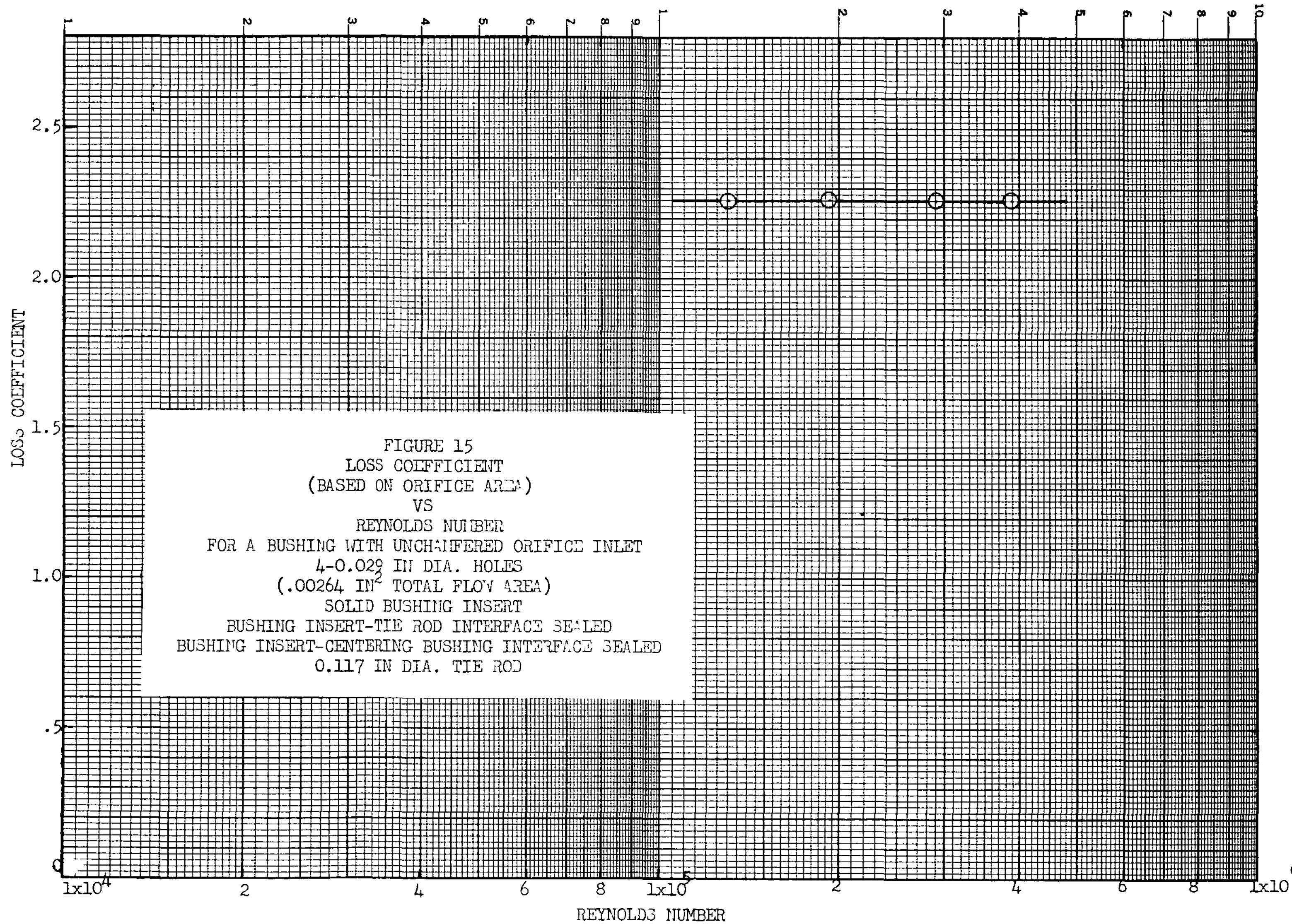

FIGURE 15
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN DIA. HOLES
(.00264 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN DIA. TIE ROD

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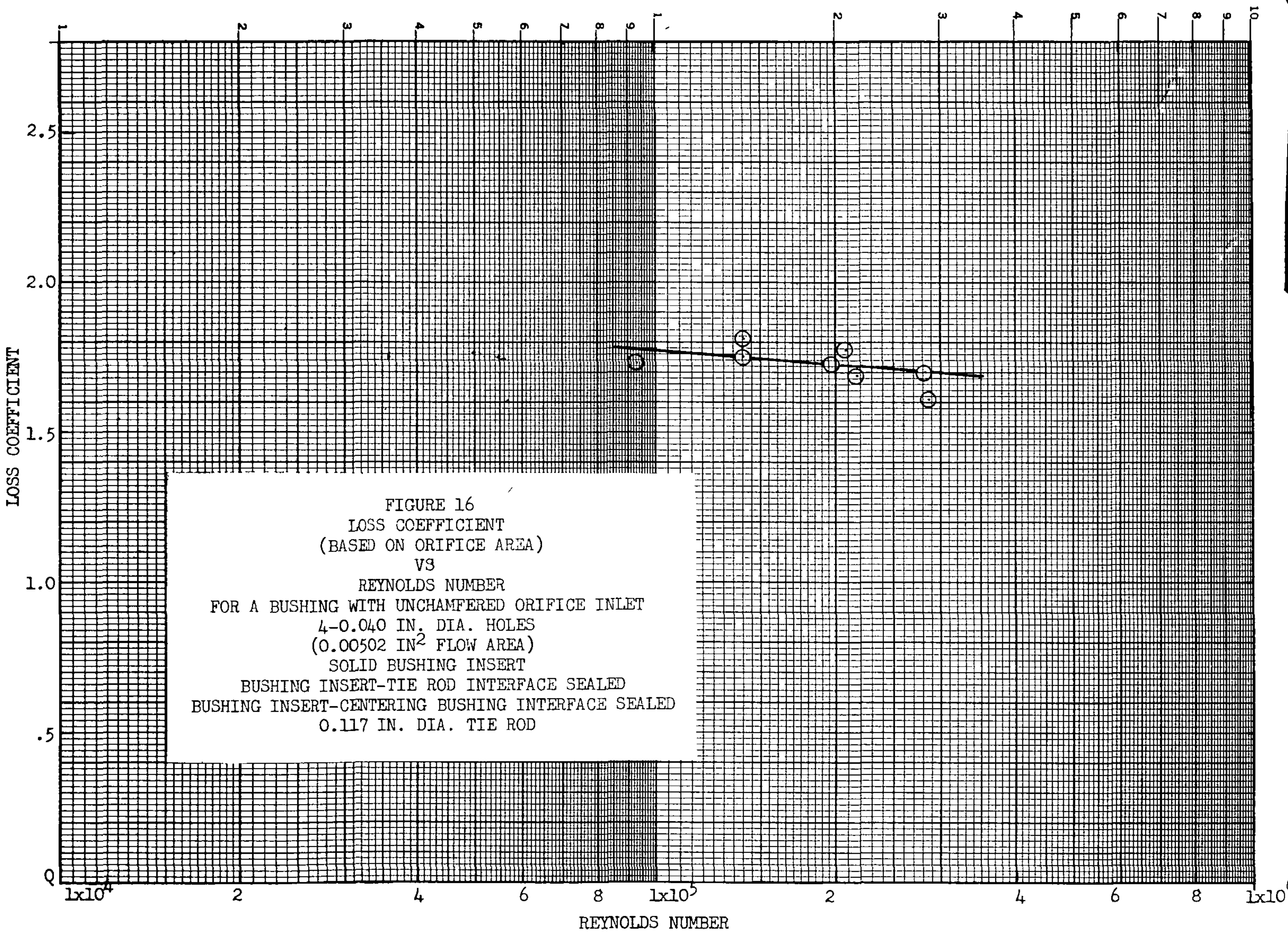

FIGURE 16
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.040 IN. DIA. HOLES
(0.00502 IN^2 FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA. TIE ROD

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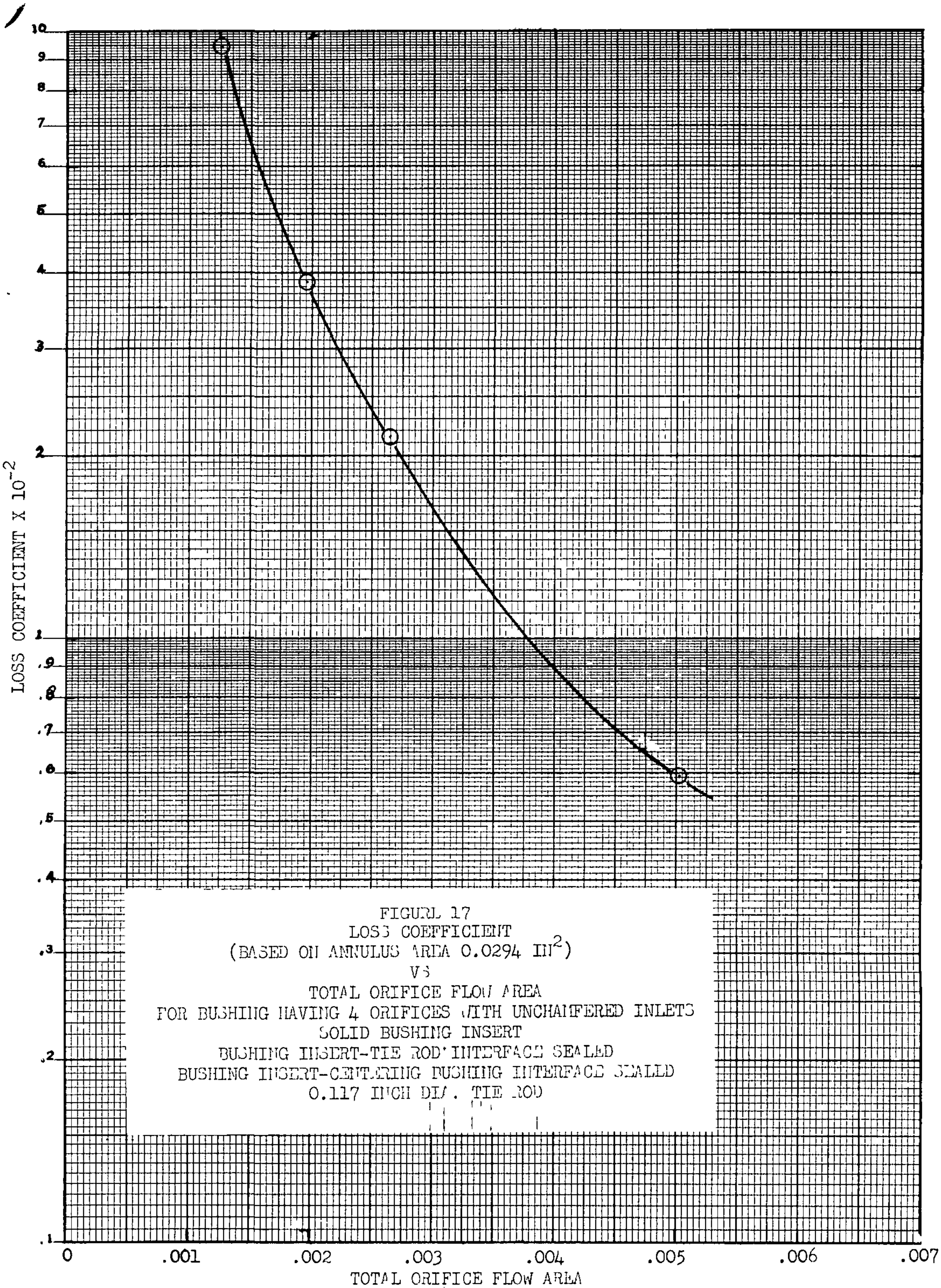

FIGURE 17
LOSS COEFFICIENT
(BASED ON ANNULUS AREA 0.0294 IN^2)
VS
TOTAL ORIFICE FLOW AREA
FOR BUSHING HAVING 4 ORIFICES WITH UNCHAMFERED INLETS
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 INCH DIA. TIE ROD

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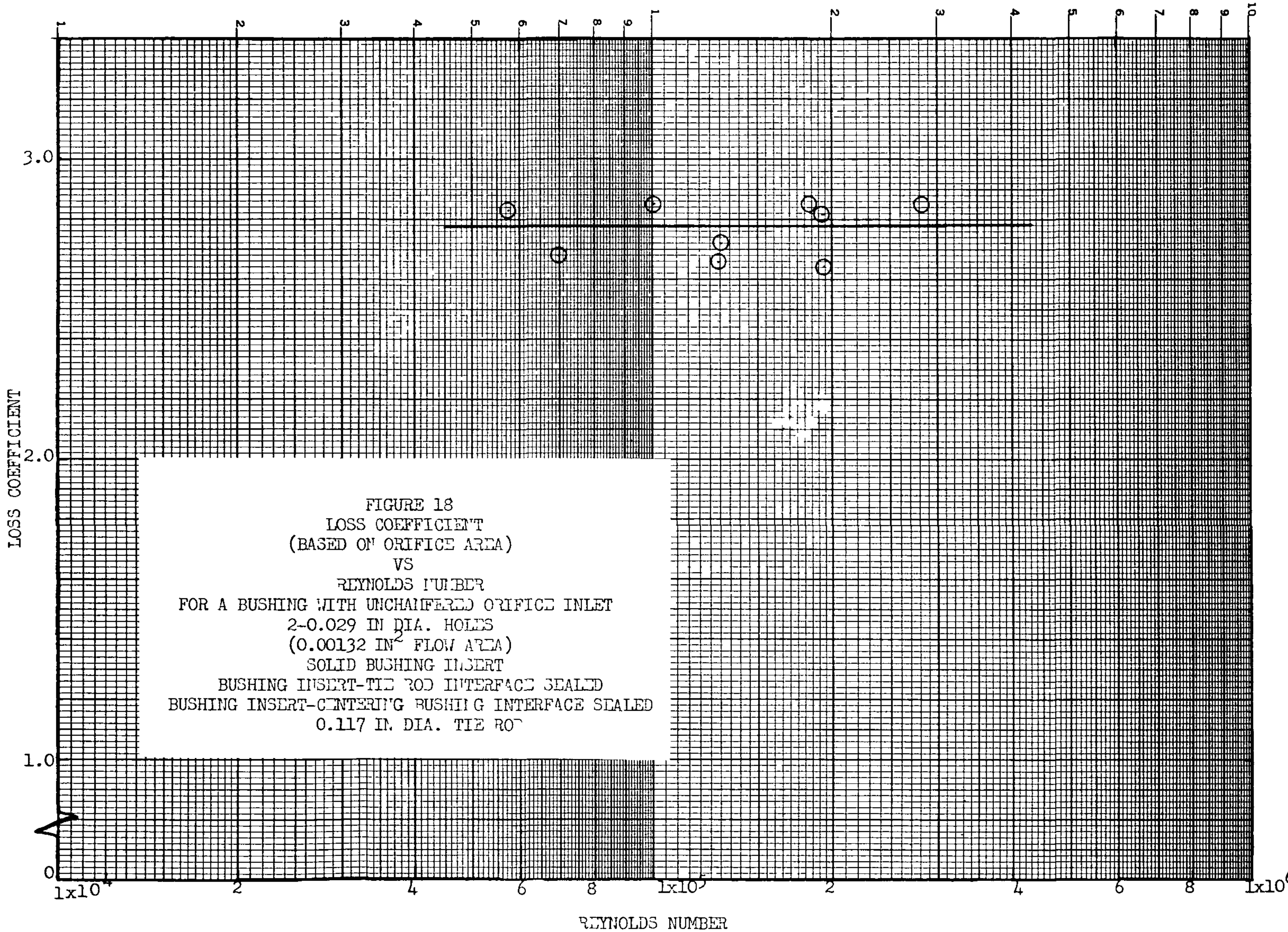

FIGURE 18
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A BUSHING WITH UNCHAMFERED ORIFICE INLET
2-0.029 IN DIA. HOLES
(0.00132 IN^2 FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA. TIE ROD

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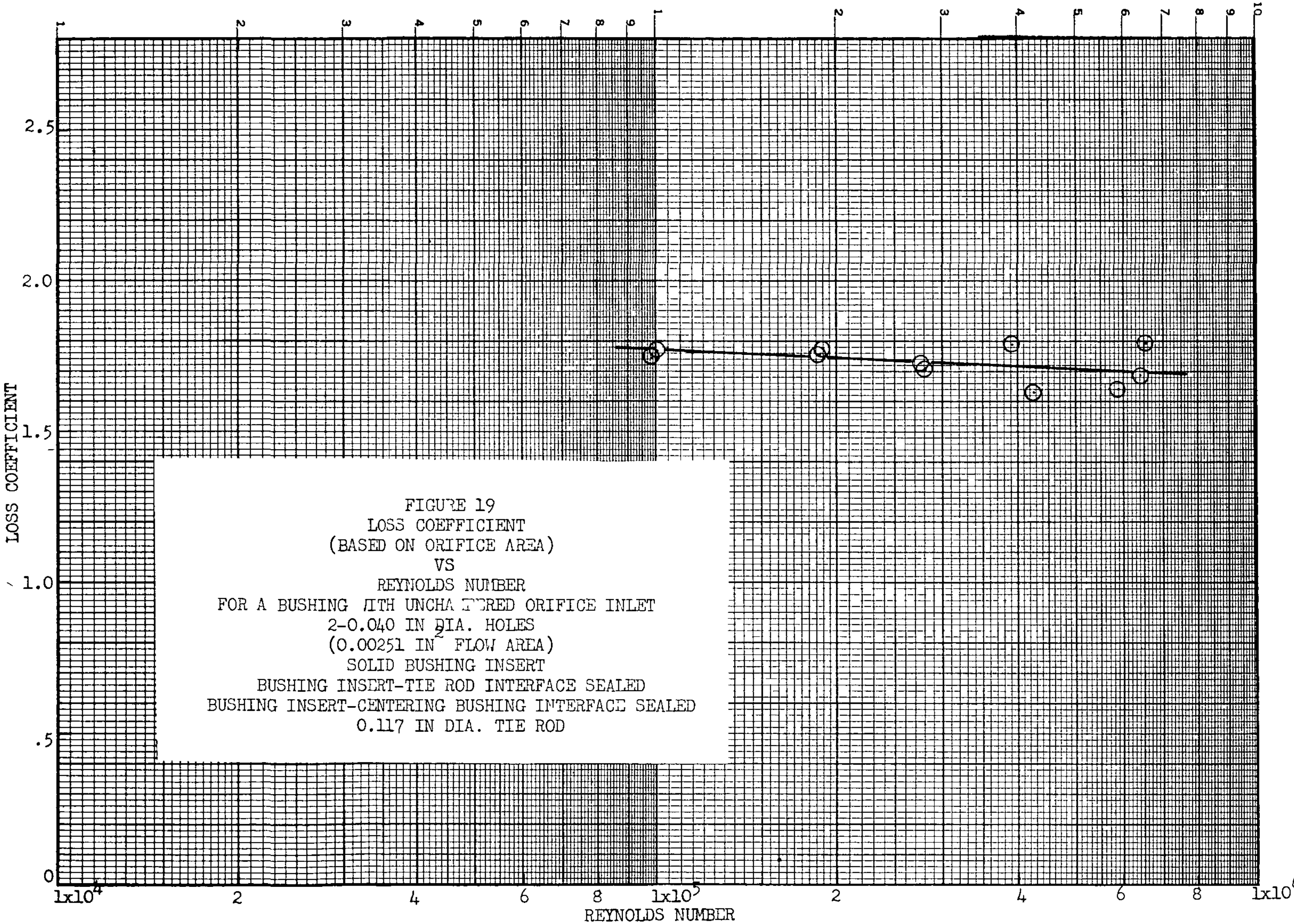

FIGURE 19
LOSS COEFFICIENT
(BASED ON ORIFICE AREA)
VS
REYNOLDS NUMBER
FOR A BUSHING WITH UNCHAMFERED ORIFICE INLET
2-0.040 IN DIA. HOLES
(0.00251 IN^2 FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN DIA. TIE ROD

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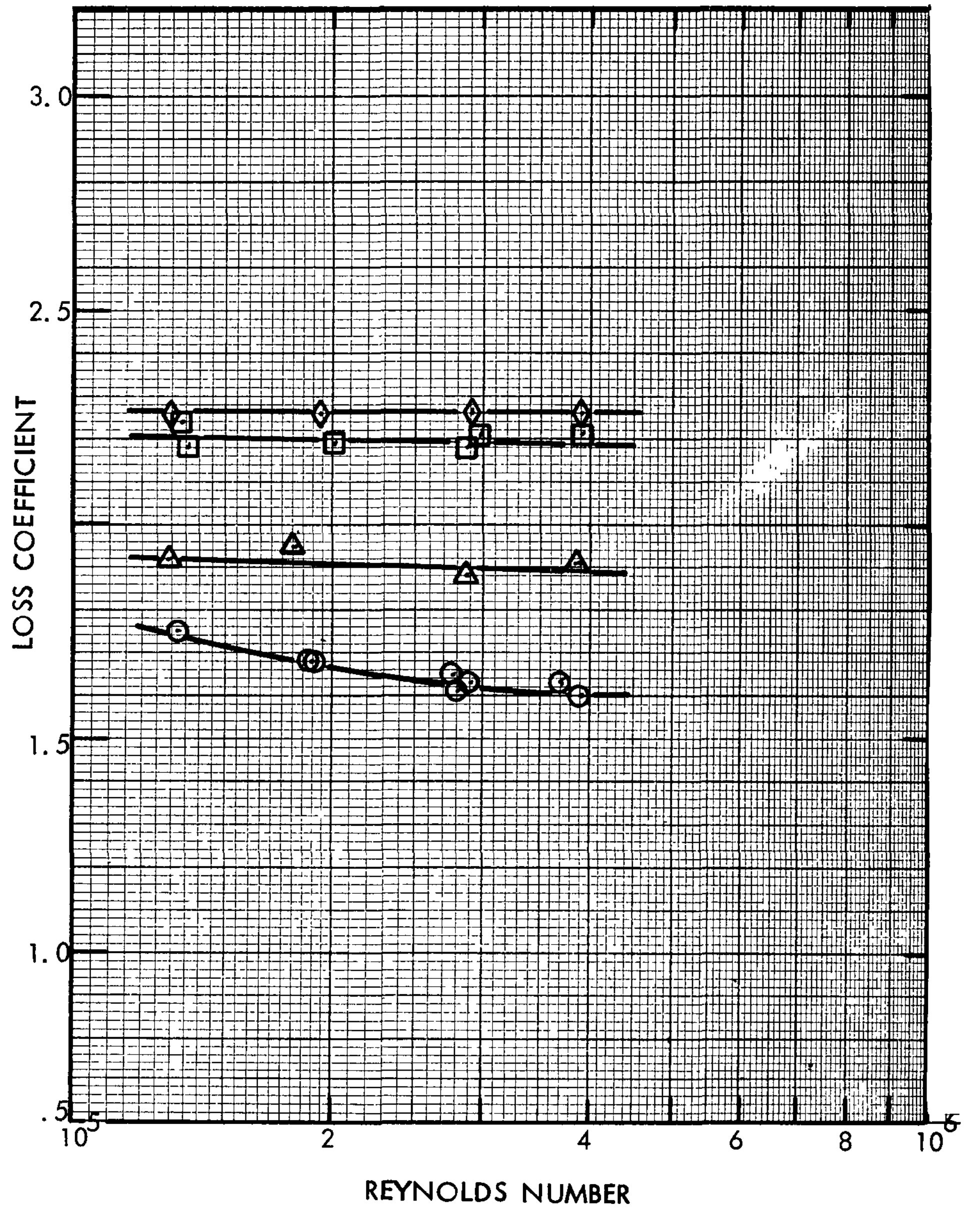

FIGURE 20

LOSS COEFFICIENT (BASED ON ORIFICE AREA) VS REYNOLDS NUMBER FOR A CENTERING BUSHING HAVING VARIOUS LEAKAGE CONDITIONS
4-.029 IN. DIA UNCHAMFERED ORIFICES

SYMBOL	◊	○	△	□
BUSHING	SOLID	SPLIT	SOLID	SOLID
BUSHING INSERT-TIE ROD INTERFACE	SEALED	SEALED	UNSEALED	SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE	SEALED	SEALED	SEALED	UNSEALED

[redacted]

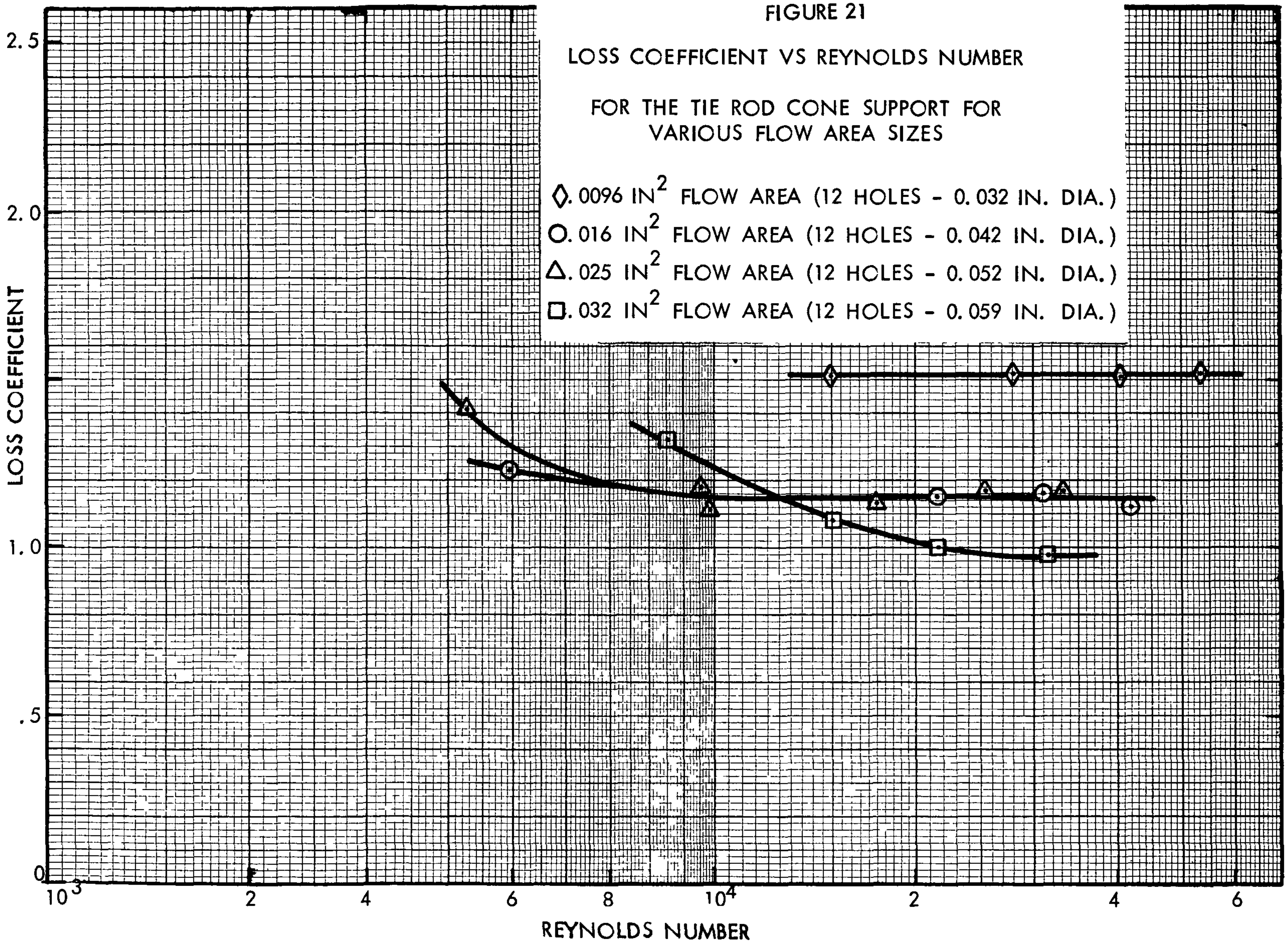

FIGURE 21

LOSS COEFFICIENT VS REYNOLDS NUMBER

FOR THE TIE ROD CONE SUPPORT FOR VARIOUS FLOW AREA SIZES

◊ .0096 IN^2 FLOW AREA (12 HOLES - 0.032 IN. DIA.)
○ .016 IN^2 FLOW AREA (12 HOLES - 0.042 IN. DIA.)
△ .025 IN^2 FLOW AREA (12 HOLES - 0.052 IN. DIA.)
□ .032 IN^2 FLOW AREA (12 HOLES - 0.059 IN. DIA.)

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TABLE 1 - FLOW TEST DATA

TIE ROD HOLDER

TOTAL Flow Area (In^2)	W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
Holder						
0.0394	10.4	182	674.4	0.0491	2.85	2.303×10^3
	15.0	162	674.4	0.0982	3.10	3.571
	24.4	155	674.4	0.245	2.97	6.025
	34.0	152	654.4	0.464	2.88	8.458
0.078	18.0	149	264.5	0.172	6.11	2.779
	15.0	147	423.5	0.074	6.16	2.298
	19.8	147	414.5	0.138	6.46	3.045
	24.2	147	414.5	0.196	6.16	3.722
	29.0	148	420.5	0.270	5.96	4.442
	33.4	147	674.5	0.220	6.00	4.923
	43.6	148	684.5	0.417	6.60	6.397
0.113	14.6	152	414.4	0.049	8.80	1.663
	19.7	152	414.4	0.093	9.05	2.244
	19.8	152	674.4	0.0491	7.85	2.163
	29.1	151	674.4	0.118	8.60	3.191
	29.8	150	414.4	0.196	8.40	3.420
	38.2	152	674.4	0.196	8.40	4.173
	47.4	156	678.4	0.344	9.20	5.103
0.132	28.7	142	675.5	0.098	10.70	2.897

TABLE 1 - FLOW TEST DATA (CONTINUED)

CENTERING BUSHING WITH CHAMFERED ORIFICE INLET
4-HOLES-0.062 IN. DIA
(.012 in^2 TOTAL AREA)

W(lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
15.9	150	674.3	0.325	0.898	1.0162×10^5
18.8	140	674.6	0.490	1.040	1.2557
20.0	147	669.3	0.515	0.898	1.2930
24.9	150	674.3	0.891	0.891	1.5915
25.1	140	644.6	0.780	0.975	1.6797
29.4	145	649.3	1.15	0.935	1.9295

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.020 IN. DIA HOLES
(.001256 in^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W(lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
6.0	206	674.7	10.7	1.68	9.72×10^4
10.6	189	674.7	32.0	1.73	18.06
10.6	193	674.7	32.5	1.74	17.83
15.2	181	674.7	62.2	1.73	26.59
15.3	183	674.7	65.8	1.77	26.58
22.1	171	674.7	131.0	1.78	39.97

TABLE 1 - FLOW TEST DATA (CONTINUED)

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.025 IN. DIA HOLES
(.00196 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
10.6	192	674.6	13.4	1.76	14.50×10^4
15.2	191	674.6	27.1	1.77	20.60
15.2	179	674.6	24.9	1.68	21.42
15.4	175	674.6	24.7	1.71	22.00
22.1	174	674.6	52.8	1.72	31.66
22.3	176	674.6	53.9	1.75	31.70
22.3	171	674.6	50.4	1.66	32.38
29.1	172	674.6	91.8	1.75	42.00
29.4	169	674.6	87.4	1.69	42.98

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN. DIA HOLES
(.00264 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
10.4	167	674.4	7.8	2.26	13.1×10^4
15.1	163	674.4	15.9	2.26	19.3
22.0	155	674.4	32.5	2.26	29.1
29.0	151	674.4	54.6	2.26	39.0

TABLE 1 - FLOW TEST DATA (CONTINUED)

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.040 IN. DIA HOLES
(0.00502 IN^2 FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
10.7	182	674.6	1.9	1.73	9.32×10^4
15.3	168	674.6	3.8	1.81	14.02
15.3	168	674.6	3.6	1.75	14.02
21.9	172	674.6	7.6	1.73	19.80
22.1	158	674.6	7.4	1.77	20.99
22.3	152	674.6	6.8	1.69	21.72
29.3	155	674.6	12.0	1.70	28.23
29.4	151	674.6	11.1	1.61	28.74

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
2-0.029 IN. DIA HOLES
(0.00132 IN^2 FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
5.9	255	674.3	18.4	2.83	5.75×10^4
10.4	199	674.3	45.8	2.85	10.1
15.0	175	674.3	85.0	2.85	18.4
15.1	165	674.3	79.5	2.82	19.3
10.5	171	674.3	38.5	2.72	13.1
5.9	185	674.3	12.8	2.68	7.0
10.5	173	674.3	38.2	2.66	12.9
15.2	165	674.3	74.9	2.64	19.4
22.0	163	674.3	172.0	2.85	28.2

TABLE I - FLOW TEST DATA (CONTINUED)
CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
2-0.040 IN. DIA HOLES
(0.00251 IN^2 FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W(lbs/hr)	T_1 (^oR)	P_1 (psia)	ΔP (psi)	C	Re
5.9	186	674.5	2.4	1.77	10.14×10^4
5.95	194	674.5	2.5	1.75	9.96
10.5	173	674.5	7.1	1.76	18.86
10.6	173	674.5	7.2	1.77	19.04
15.1	166	674.5	13.9	1.73	27.88
15.1	163	674.5	13.4	1.71	28.16
21.5	169	674.5	30.5	1.79	39.28
22.0	160	674.5	28.2	1.69	64.40
22.0	153	674.5	25.8	1.63	42.70
28.9	148	674.5	43.6	1.64	59.14
29.0	156	674.5	50.0	1.79	65.48

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN. DIA HOLES
(.00264 IN^2 TOTAL FLOW AREA)
UNSEALED SPLIT BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.110 IN. DIA TIE ROD

W(lbs/hr)	T_1 (^oR)	P_1 (psia)	ΔP (psi)	C	Re
10.7	181	674.6	6.8	1.75	13.2×10^4
15.3	172	674.6	12.6	1.68	18.9
15.3	172	674.6	12.8	1.68	19.0
22.1	169	674.6	25.8	1.65	27.7
22.2	167	674.6	26.1	1.61	28.0
22.4	161	674.6	24.6	1.63	29.0
29.1	165	674.6	43.7	1.63	37.0
29.1	154	674.6	40.5	1.60	39.0

TABLE I - FLOW TEST DATA (CONTINUED)
CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN. DIA HOLES
(.00264 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE UNSEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.117 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
5.7	193	672.4	2.7	2.13	6.6×10^4
10.6	179	674.4	7.2	1.92	12.9
14.3	167	674.4	13.8	1.95	18.0
22.0	157	674.4	27.2	1.88	28.8
29.0	153	674.4	46.9	1.91	38.7

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN. DIA HOLES
(.00264 IN^2 TOTAL FLOW AREA)
SOLID BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE UNSEALED
0.117 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
5.8	239	674.3	3.3	2.24	5.9×10^4
6.0	175	674.3	2.6	2.19	7.35
10.5	165	674.3	7.2	2.24	13.4
10.7	165	674.3	7.7	2.18	13.6
15.2	155	674.3	14.7	2.19	20.2
22.0	159	674.3	31.4	2.18	28.7
22.0	149	674.3	30.6	2.21	29.8
29.0	149	674.3	52.8	2.21	39.3

TABLE I - FLOW TEST DATA (CONTINUED)
CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN. DIA HOLES
(.00264 IN^2 TOTAL FLOW AREA)
UNSEALED SPLIT BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE UNSEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE SEALED
0.110 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
6.1	184	674.5	2.4	1.86	7.3×10^4
10.6	164	674.5	5.9	1.69	13.6
15.4	154	674.5	11.3	1.63	20.4
22.4	152	674.5	23.3	1.60	30.0
22.5	152	674.5	22.6	1.56	30.1
22.5	147	674.5	21.8	1.55	29.6
29.8	148	674.5	38.9	1.59	40.5

CENTERING BUSHING WITH UNCHAMFERED ORIFICE INLET
4-0.029 IN. DIA HOLES
(.00264 IN^2 TOTAL FLOW AREA)
UNSEALED SPLIT BUSHING INSERT
BUSHING INSERT-TIE ROD INTERFACE SEALED
BUSHING INSERT-CENTERING BUSHING INTERFACE UNSEALED
0.110 IN. DIA TIE ROD

W (lbs/hr)	T_1 (°R)	P_1 (psia)	ΔP (psi)	C	Re
6.0	196	674.3	1.8	1.37	6.9×10^4
10.4	172	674.3	4.7	1.33	12.9
10.6	174	674.3	5.1	1.39	13.1
15.0	176	674.3	11.1	1.47	18.3
15.2	155	674.3	9.1	1.36	20.1
15.4	158	674.3	9.9	1.39	20.1
22.0	158	674.3	19.6	1.34	28.7
22.1	148	674.3	17.7	1.29	30.0
29.0	153	674.3	32.4	1.32	38.7
29.0	145	674.3	28.8	1.23	40.0

TABLE I - FLOW TEST DATA (con't)

TIE ROD CONE SUPPORT

AREA	W (lbs/hr)	T_1 (^oR)	P_1 (psia)	ΔP (psi)	C	Re
.030 Holes Nominal,	7.9	516	574.6	0.88	1.51	1.4903×10^4
Actual Flow Area	14.8	513	572.6	3.1	1.52	2.8112
.00957 in^2	21.3	508	576.6	6.2	1.51	4.0681
	27.9	505	574.6	10.8	1.52	5.3452
0.040 Holes Nominal,	3.46	526	554.6	0.0491	1.23	.4975
Actual Flow Area	14.8	511	563.6	0.835	1.15	2.1664
0.01625 in^2	21.2	510	564.6	1.71	1.16	3.1033
	28.5	503	574.6	2.9	1.12	4.2080
0.050 Holes Nominal,	3.63	509	572.6	0.0245	1.41	.4279
Actual Flow Area	8.1	494	574.6	0.0982	1.18	.9569
0.025 in^2	8.3	504	576.6	0.0982	1.10	.9831
	14.8	504	574.6	0.32	1.13	1.7529
	21.5	504	569.6	0.71	1.17	2.5509
	28.0	498	576.6	1.18	1.17	3.3452
0.059 Holes Nominal,	8.3	518	574.5	0.074	1.32	.8524
Actual Flow Area	14.7	518	574.5	0.186	1.08	1.5097
0.032 in^2	21.0	513	574.5	0.363	1.00	2.1751
	30.3	507	584.5	0.725	0.98	3.1654